Virtual Cockpit Simulation for Pilot Training

Dipl-Ing. Kai-Uwe Dörr, Dipl.Inform. Jens Schiefele & Prof. Dr.-Ing. W. Kubbat[1]
Institute for Flight Mechanics and Control
Technical University Darmstadt
Petersenstraße 30
64287 Darmstadt
Germany

Summary

For some of today's simulations very expensive, heavy, and large equipment is needed. Examples are driving, shipping, and flight simulators with huge and expensive visual and motion systems.

In order to reduce cost, immersive 'Virtual Simulation' becomes very attractive. Head Mounted Displays (HMD) or CAVEs (Computer Animated Virtual Environments), Datagloves, and cheap 'SeatingBucks' are used to generate a stereoscopic virtual environment (VE) for the trainee.

IVS enhances training quality and quantity for classroom-teaching and Computer Based Training (CBT). It allows to visualize and animate teaching-material in a more natural stereoscopic environment. Data of before unseen complexity can be revealed and complex models easily visualized. For the first time, the trainee himself can interact with a Data-Glove in the environment and collect cockpit experience long before his maiden flight. CAVEs and Immersive Projection Screens enable "group training" to collect personal and shared experience while further enhancing training quality.

With increasing maturity of VR-gear IVS will allow to generate new training metaphors for immersive flight simulation. This might include the enhancement or partial replacement of conventional flight simulators by IVS.

Introduction

High fidelity pilot training simulators are designed as training tools for one specific aircraft type. They demand authentic instrumentation and system layout for the simulated aircraft type including huge outside vision systems and cumbersome motion systems.[1] Because of these reasons, traditional simulators are very expensive, inflexible, and difficult to reconfigure. The high cost factor in buying and maintaining them causes air carriers to purchase either just a single simulator for every aircraft type they own or to buy expensive training hours from other companies.[1]

Virtual Simulation

To overcome some of the problems in the field of pilot training the Air Force Institute of Technology developed a Virtual Cockpit (VC) for fighter pilot training.[2] Pilots are immersed in a stereoscopic VE, wearing a HMD and a pointing device to interact with the virtual cockpit devices.[3] A VC can be easily reconfigured by simply switching the cockpit model database and the attached flight mechanics.[4] At the Institute for Flight Mechanics and Control, Darmstadt University of Technology this concept was extended to be suitable for an Airbus A340 Cockpit-IVS using hi-resolution HMD, "Seating Buck", cyberglove, and stereoscopic projection screens for a natural interaction metaphor.[5] As pilot outputs for principle navigation and Instrument Flight Rule (IFR) testing a virtual Primary Flight Display (PFD), a virtual Navigation Display (ND), and a virtual civil Head-Up Display (HUD) are available. In addition, a simplified outside visual is rendered to the pilot. These displays are sufficient to run principle Instrument Flight Rule (IFR) tests with the virtual cockpit.

The problem of lacking force feedback in IVS was significantly reduced by developing a "Seating Buck".[6] Only side-stick, pedals, flap-lever, and thrust-lever are physically available. All other buttons, dials, and switches are simulated by simple plastic panels. In a test series the concept and implementation proved to reduce interaction time significantly.[1,6]

Other examples for operator training using Virtual Training methods are Astronaut training to repair the Hubble Space Telescope[7], submarine outlook training to practice maneuvering in a harbor[8], support pilots classroom education[9], or caterpillar training. Instead of HMDs very often CAVEs[10] and BOOMs[11] are used to avoid heavy intrusive head gear and limited Field of Views (FOV).

Human Machine Interface in Virtual Simulation

Transfer of training from virtual into real space still has to be proven for pilot training. For simple Cola can sorting in a CAVE transfer of training from virtual into real space was shown.[12,13] Also, people trained in VR have a better orientation in buildings than map trained persons[14]. Therefore, it can be assumed that training in virtual environments might be useful to train trainees at different requirement levels.

Training quality limiting factors due to today's hardware equipment such as Field of View (FOV)[15,16,17,21], tracker

[1] For contact with authors: doerr@fmr.tu-darmstadt.de; schief@fmr.tu-darmstadt.de; kubbat@fmr.tu-darmstadt.de; tel. +49 6151 16 2890, fax +49 6151 16 5434

latency[18], presence[19], and missing force feedback[1,6] were investigated in principal. Only few research exists determining the limitations on training caused by the complete VR-Human Machine Interface (HMI) design and hardware.[20]

VR-HMI research has already been conducted concerning force feedback, HMD FOV, and HMD resolution for Cockpit-IVS.[1,6,21]

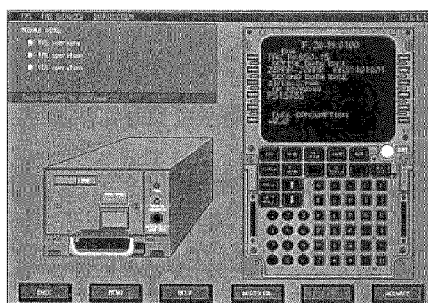A good general overview describing VR-HMI research is presented in [22].

Conventional Computer-Based Training

Computer Based Training and Procedure Training (PT) use PCs with a 2D image, sound, a mouse, and a keyboard for interaction. A trainee sits in-front of a PC screen and interacts by clicking with the mouse. CBT is split into different chapters such as radio navigation, flight planing, flight performance, electronics, instrumentation, and engines. Further enhanced systems allow partial simulation of functionality. For each individual aircraft type a different program is available. Each individual chapter is split into different learning units:

- Overview
- Components and Control
- System Operation
- Abnormal Operation
- Summary
- Mastery Test

In different learning units the trainee gets a multimedia presentation of the learning material. After the introduction, the trainee can interact with the system by clicking with the mouse on interaction devices. In the Mastery Test multiple choice questions have to be answered and tasks performed. The trainee can practice all units on his own personal learning pace. The test can also be individually repeated.

Such a training metaphor helps to support individual training. "Fast learner" are not frustrated by a low pace and "slow learner" are not overrun.
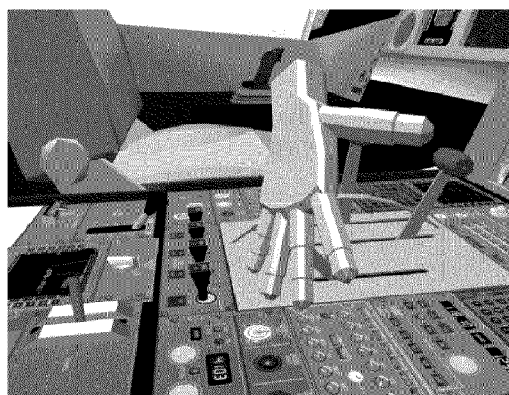

Figure 1: Flight management computer training with CBT

The trainee does not have any immersive experience towards the real geometry and functionality of the cockpit. The position of interaction devices in real 3D space is unknown to him. Familiarization in 3D space can not be realized with today's CBT systems.
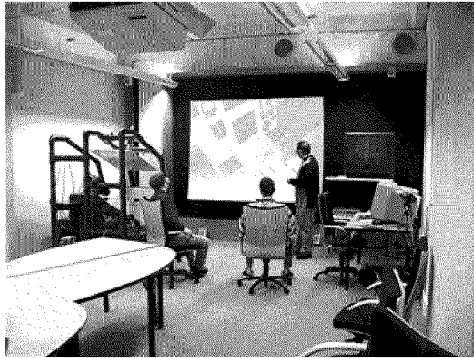
CBT with a VR Training Environment

In order to enhance CBT, a 3D Virtual Cockpit model is generated. All interaction devices such as side stick, pedals, thrust-lever, knobs, buttons, and dials are modeled as 3D geometry. All other parts and surfaces are formed by simple textured geometry.[5] This 3D model is rendered to a pilot wearing a tracked high-resolution, large field of view (FOV), stereoscopic HMD.

Figure 2: IVS Cockpit based on modeled geometry and textures

For interaction the pilot wears a tracked data-glove recognizing hand position, orientation, and finger bending. The trainee can virtually interact with all cockpit devices, dials, and buttons. The system response on the input can be visualized.

The same image is also rendered to a large stereoscopic projection screen (Shutter classes) enabling observers to watch the trainee and his interaction. This allows later discussion on the trainees performance.

Figure 3: Demonstration room with projection screen (three shutter signals)

The same concepts and structures known from ordinary CBT are applied. The only difference is that the trainee is immersed into the scene allowing him to interact naturally with his environment. Learning aids and eye catchers such as symbols, markers, and any desired virtual information can be visualized within the 3D virtual cockpit as well. For instance, after toggling the gear lever the virtual gear unit is displayed and the actuator changes visualized. Therefore, beyond the VR simulation of an ordinary cockpit, virtual information can be incorporated and used as didactical metaphor for pilot training.
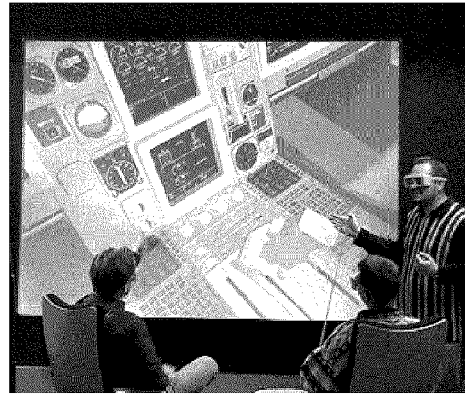
Therefore two different Training methods are feasible with this environment. In the so called Class Room Training, collective and cooperative learning in front of a single projection screen enables trainees to work and learn together in the same environment.

As a second training method, a single VR-Pilot training environment was developed. Therefore the trainee wears a HMD and a Data Glove. Both devices were tracked with a tracking system. So a naturally interaction with the virtual scene is possible. The trainee is guided trough the different lessons depending on his interaction with the cockpit The trainee itself define which lesson he wants to work through . Additionally it is possible for the trainee to fly with this virtual cockpit because of its full functionality. Both Methods uses the same Training lessons with minimum changes in interaction possibilities. Example lectures were realized for both training methods and will be described later on.

Classroom Training
The didactical methods for training vary depending on the airlines and the training facilities. Training is often based on the conventional concept of "frontal teaching". Teachers give lectures with varying didactical materials. Dependent on the training facility this can be simple transparencies, video-tapes, sketches, boards, and small mockups. After each lecture the trainee has the possibility to re-read the taught lecture from printed

material. At the end of each training chapters pilots must pass a written multiple choice test.

Figure 4: Stereoscopic projection screen for classroom training

Hence, the understanding of complex aircraft systems strongly depends on the imagination of a trainee and the teaching skills of a teacher. In order to enhance teaching quality stereoscopic projection screens can be used to visualize complex aircraft systems and technical dependencies in a natural way. A teacher can fly through a model, hide obstructing parts, or animate complex functionality's. The trainee himself becomes part of the scene. In after lecture sessions the trainee can interact with the system and its functionality. In front of an immersive screen the trainee becomes part of the scene and experiences the learn material more naturally. Stereoscopic vision with depth perception enables new pilots to easily asses complex 3D structures, aircraft positions, etc. The "hands-on experience" helps to deepen the understanding and motivate the trainee to explore deeper into the learning material. Group experience and group training can be enhanced with an stereoscopic projection system. This might accelerate memorization and pushes the later needed ability of cooperative cockpit work through group experience.

VR Pilot Training
For today's simulator training huge and expensive simulators are needed. Each training hour costs up to $5,000 and existing training facilities are currently at the limits of their capacities. Additional to the later on described training lessons, the system is also fit for use, to train some real flight tasks. Therefore, the Virtual Cockpit (VC) based on the above described technique (HMD plus Stereoscopic Projection Screen) can be used. In addition to the CBT approach, a simplified outside visual is added to generate an immersive flight simulation. The viewing distance has to be reduced to approximately 20km in order to ensure sufficient rendering performance (15–20Hz). A virtual Primary Flight Display (PFD), Navigation Display (ND), and a virtual stereoscopic Head Up Display (HUD) are used in a first approach.[21]

Figure 5: Primary flight display and navigation display

These virtual displays show basic information necessary to perform a controlled flight and allow basic performance analysis with the system.
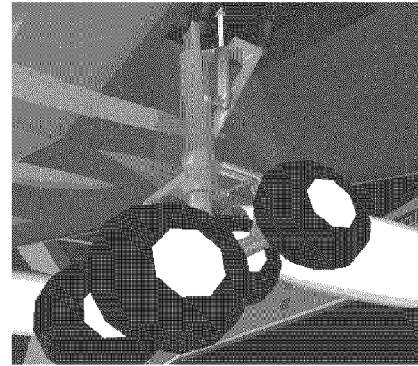
Aircraft System Lesson

Aircraft system knowledge is one of the main training parts during theoretical pilot education. Simple system diagrams are used to give the trainees an overview of the whole system. Relations between aircraft subsystems and how these systems work together will be explained in the same way. This is not a very intuitive way of learning. The best way to learn is to visualize them. The visual channel is the most significant way to comprehend information.

The main advantage of VR-systems is the possibility to display trainees a 3D geometry of an object and a simulation of the real behavior. As an example the behavior of gear, flaps, and rudder on an input from the pilot is shown. Therefore, a complete aircraft model is shown to the trainee (Figure 6). The model shows the reaction of the aircraft and it is possible for the trainee to zoom in different subsystems.

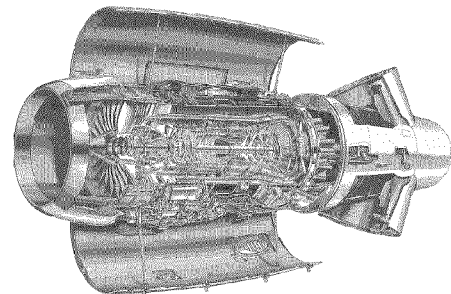**Figure 6:** Aircraft outside view above the pedestal

Figure 7: Gear view

In this example (Figure 7) the trainee can observe the kinematics of the gear. He can imagine the 3D behavior of the actuators during gear up and down procedure. So, in case of a system failure, he can imagine what is happen and where the errors can be. The system knowledge increases because of the 3 dimensional form of presentation.
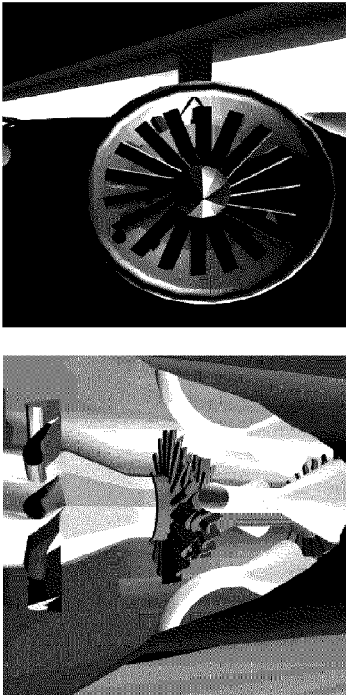
Engine Lesson

During pilot education engines are visualized by explosion sketches or vertical cuts through an engine. This creates a complex visualization of the parts. For instance, explaining the turbine turn rate at N1 and N2 is rather difficult. Either the graphical representation is showing too much or too view detail, forcing the instructor to switch between several images.

Figure 8: Conventional visualization with a cut through an engine

Therefore, a lecture was developed that allows to dismantle the engine from a full blown representation down to the necessary key elements such as fan, turbine stators, turbine shaft, and combustion chamber. Trainees observe the animated engine and can position themselves on arbitrary positions.

Figure 9: 3D engine inside view

Alternatively the they can follow a prerecorded flight path through the scene. During the flight they can arbitrary change the viewing direction. They can always stop and move towards any object to get a closer look. To increase realism and a feeling for object sizes, a complete aircraft is rendered as well.

Stereoscopic vision enables trainees to be immersed into the environment generating a closer and better impression of the turbine. It enables the trainees to achieve a feeling for real part and turbine sizes. With ordinary paper sketches this is impossible. As an enhancement, observers can be re-scaled to small sizes allowing to closely observe small turbine parts and their functionality.

Based on the stereoscopic vision, instrument locations and attached functionality can be memorized by generating a mental map of the cockpit.

Force Feedback/Vision

It was determined that lacking force feedback in pure IVS is a major usability limitation.[6] Therefore, some devices are physically available such as sidestick, pedals, and thrust-lever. All others are replaced by simple plastic panels to generate force feedback to the pilot (Seating Buck).[1] The Seating Buck can be easily reconfigured to simulate arbitrary cockpit configurations.
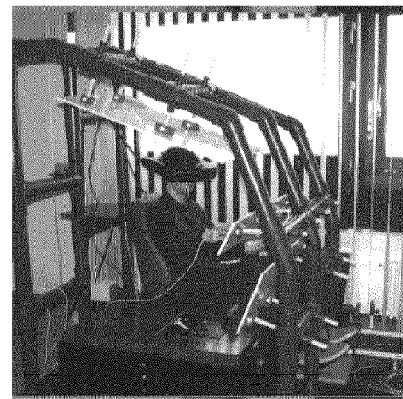
With a Seating Buck force feedback device the interaction time is reduced significantly providing a more natural haptical feedback to the pilot.[6]

For the success of a VR CBT enhancement a large FOV of more than 80° is needed.[21] Above a 60° FOV pilots can assess all visible information and geometry in the cockpit. Above a 80° FOV also orientation and cross-

viewing among two pilots simulated in the same IVS is feasible.[21]

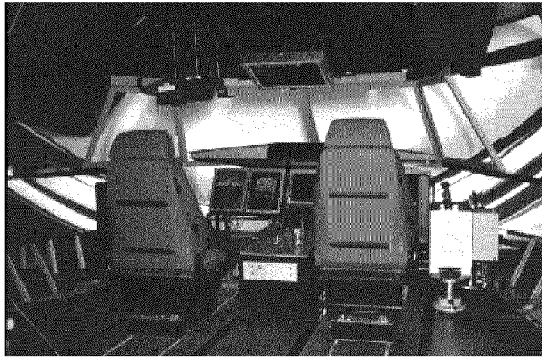**Figure 10:** Stereoscopic projection screen rendering scene visible to the pilot

Figure 11: Seating buck to simulate force feedback

Usability

VR CBT and PT system can help to reduce education cost by reducing expensive simulator hours for familiarization and principle interaction training. Otherwise, it can serve as an extension to already proven CBT training concepts. The VR technology and projection screen technology is mature enough to fulfil these tasks. HMD with the requested FOV, force feedback devices, and computers with sufficient graphics power exist. However, real verification of training transfer has to be further investigated in the future.

Flight Simulation

All ordinary software simulation modules known from conventional flight simulation such as physical input devices, virtual input devices, flight mechanics, traffic, and rendering run in a distributed environment on different high end graphics work stations. As simulation module an Airbus A300 flight mechanics, ground collision , weather, and sound modules are available. All the modules are taken from a conventional flight simulator available at the Institute for Flight Mechanics and Control.[23] It can be also used for comparing the VCS with a real flight simulation.

Figure 12: Conventional flight simulator mock-up at the FMRT

Motion Base

In addition, to the current approach of a fixed based "Seating Buck", the entire system can be mounted to a motion base. This would increase the level of immersiveness by aircraft motion. To simulate a civil aircraft the performance of small two-seater (300kg) motion bases would be sufficient. The increase in realism and immersion is untested and need to be further evaluated.

Tracker and System Lag/HMD Limitations

One of the key limitations to VC is today's tracker latency. The entire VCS has currently a latency of about 100ms.[24] From tests it was deducted that 150ms are sufficient for orientation tasks within the cockpit.[24] Maximal lag for flying a VCS should be well below 80ms.[25]

Another limitation is the currently used HMD with a FOV of maximal 56°. As stated above, this HMD reduces the FOV in a way that disables flying and orientation tasks within the cockpit. However, this is not a general concept limitation because HMD vendors already sell 120° equipment.

HMD resolution is very critical for the usability of VCS. Research results indicate that with a hires HMD of 1280x1024 pixels and cockpit displays (PFD, ND, and HUD) of 8 inch rendered at a distance of approximately 85cm (standard pilot-display distance) offers sufficient resolution.[21] Therefore, resolution with modern HMD is no more limitation to Cockpit-IVS.

Usability

The used VR equipment is critical for the success of VCS. In principal most system components such as force feedback generation, HMD FOV and resolution are proven to be usable. Tracker lack has to be reduced significantly. It is untested which influence the combination of VR equipment has on the overall performance. The usability of VCS to enhance simulator training is unproven.

Even after optimization of all VR equipment it seems unfeasible to completely replace flight simulators by VCS. In a first step the understanding of the HMI presented by intrusive, heavy, inconvenient Virtual Reality gear has to be further investigated. Also, a complete Virtual Reality simulation theory is missing. On the first impression large projection screens have less negative impact on the HMI.

Future Work

The Institute for Flight Mechanics and Control will further investigate the usability of VR-CBT and VCS. The research will be focused on the human machine interface generated through virtual simulations. The goal is to prove the usability (especially of CBT) for real usage in today's flight training.

It is assumed that the introduction of large stereoscopic projection screens into today's pilot training will be a natural step. The equipment is already usable for classroom training applications and CBT.

Available Equipment

At the Institute for Flight Mechanics and Control a variety of equipment can be used. A front projection system (Ampro Projector) with a curved screen and four shutter emitters is installed. For the system seven shutter glasses (Christal Eye) are available. For IVS a nVision Datavisor 10× (1280×1024), Kaiser ViSim500, Polhemus Fastrack, two 18 sensor Cyber-Gloves, and a triple Pipe Onyx (IR) can be used.

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